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(54) **FILTER**

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H01P 7/10 (2006.01)
H01P 1/208 (2006.01)

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CPC ***H01P 7/105*** (2013.01); ***H01P 1/2088*** (2013.01); *H01P 1/2002* (2013.01); *Y10T 29/49016* (2015.01)

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USPC 333/219.1, 202, 208
See application file for complete search history.

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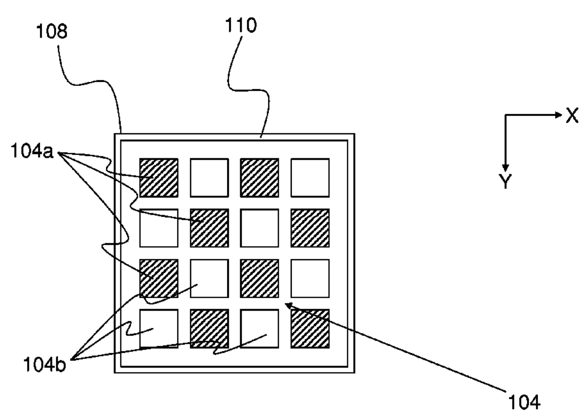
(57) **ABSTRACT**

A multi-mode cavity filter having a dielectric resonator body incorporating a piece of dielectric material, the piece of dielectric material having a shape such that it can support at least two substantially degenerate resonant modes; and a coupling structure comprising a plurality of independent coupling elements for coupling signals to the piece of dielectric material.

17 Claims, 12 Drawing Sheets



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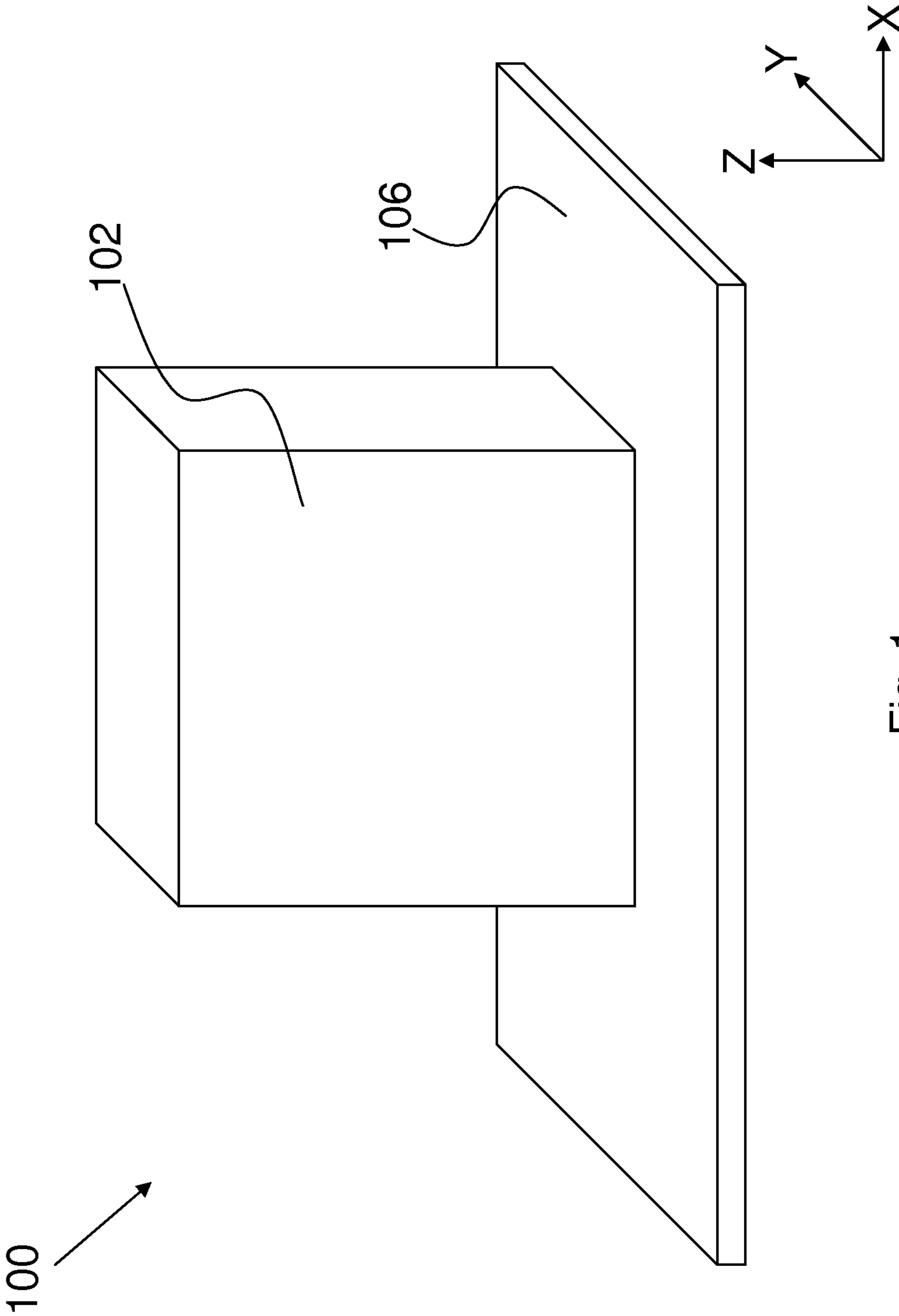

Fig. 1

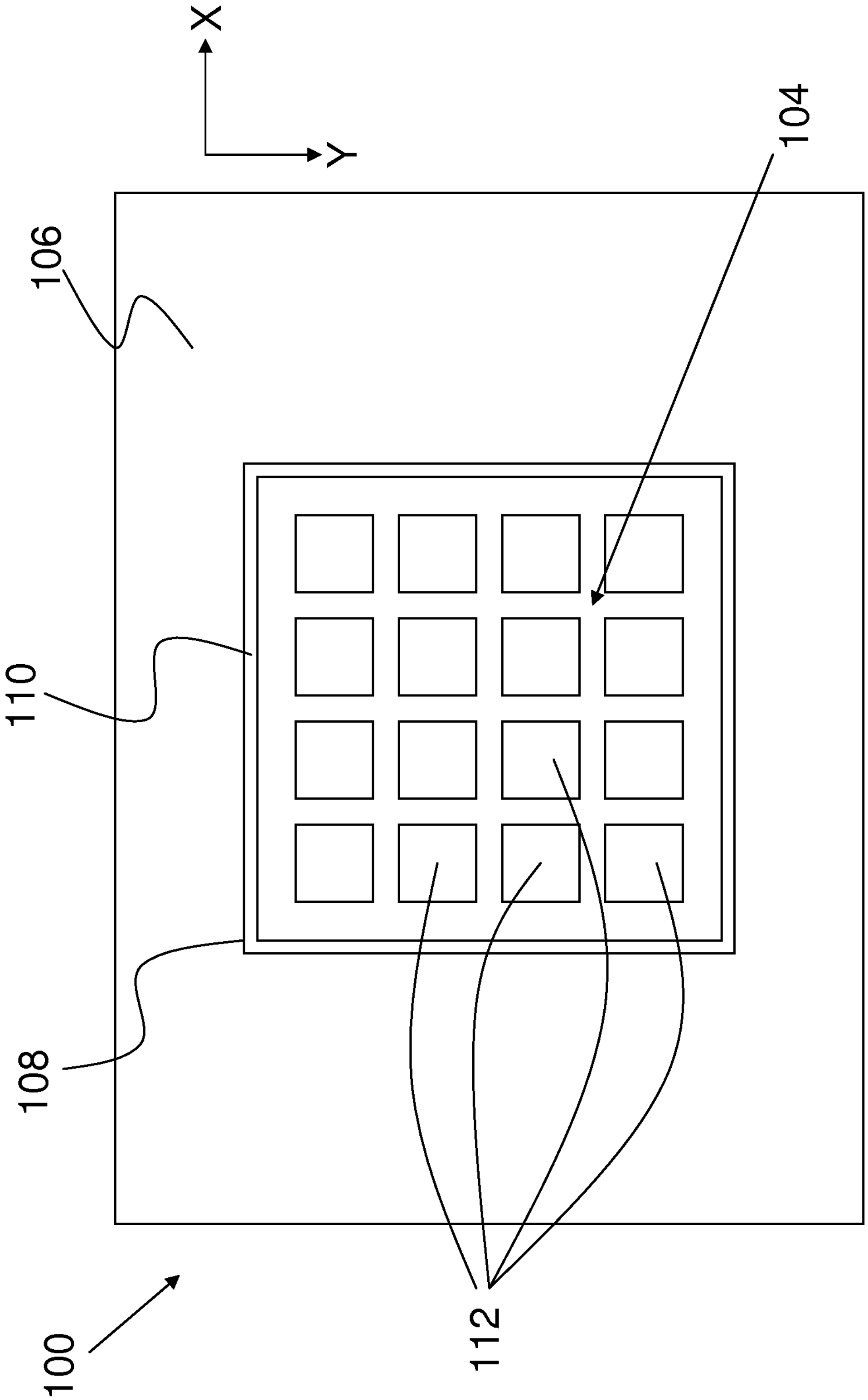

Fig. 2

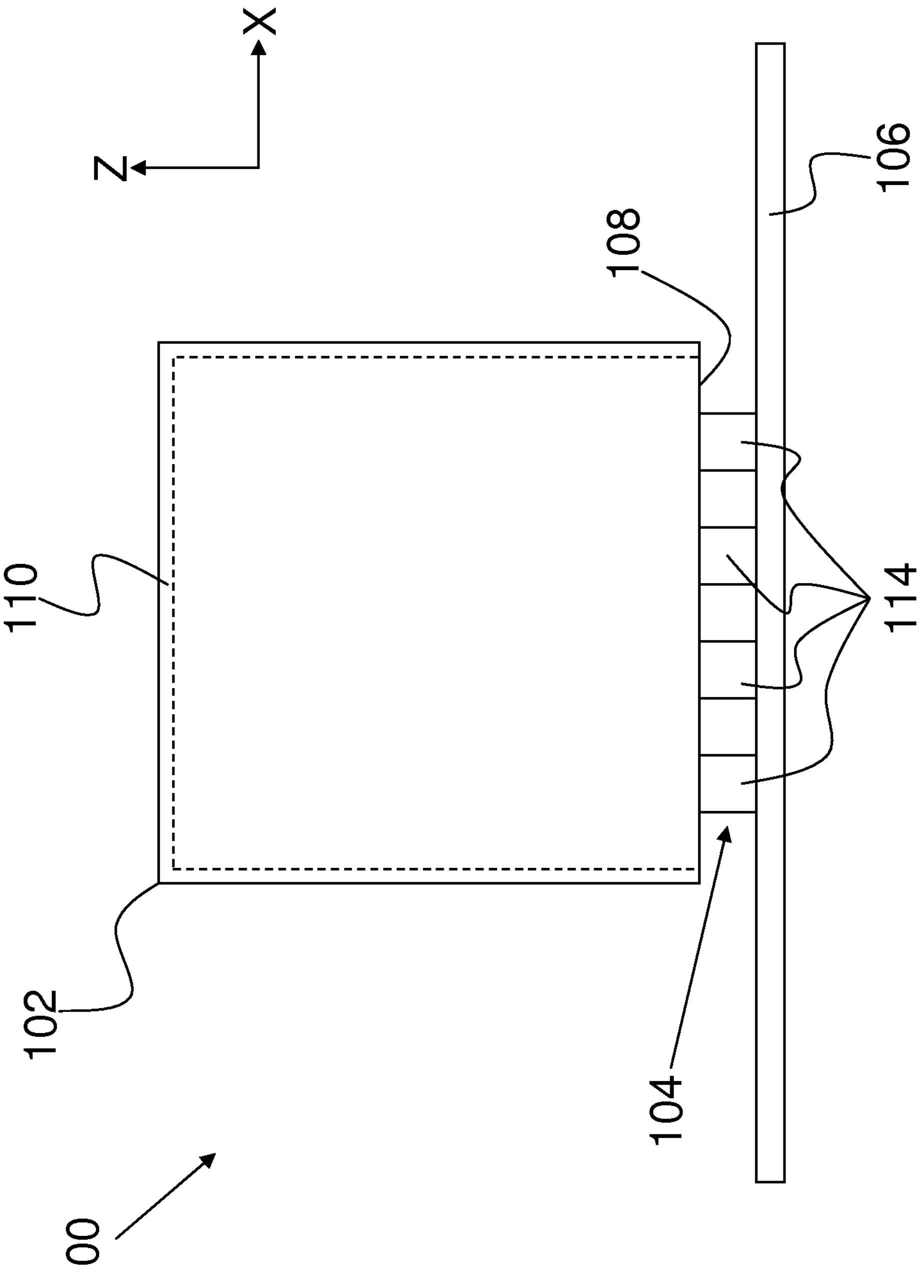

Fig. 3

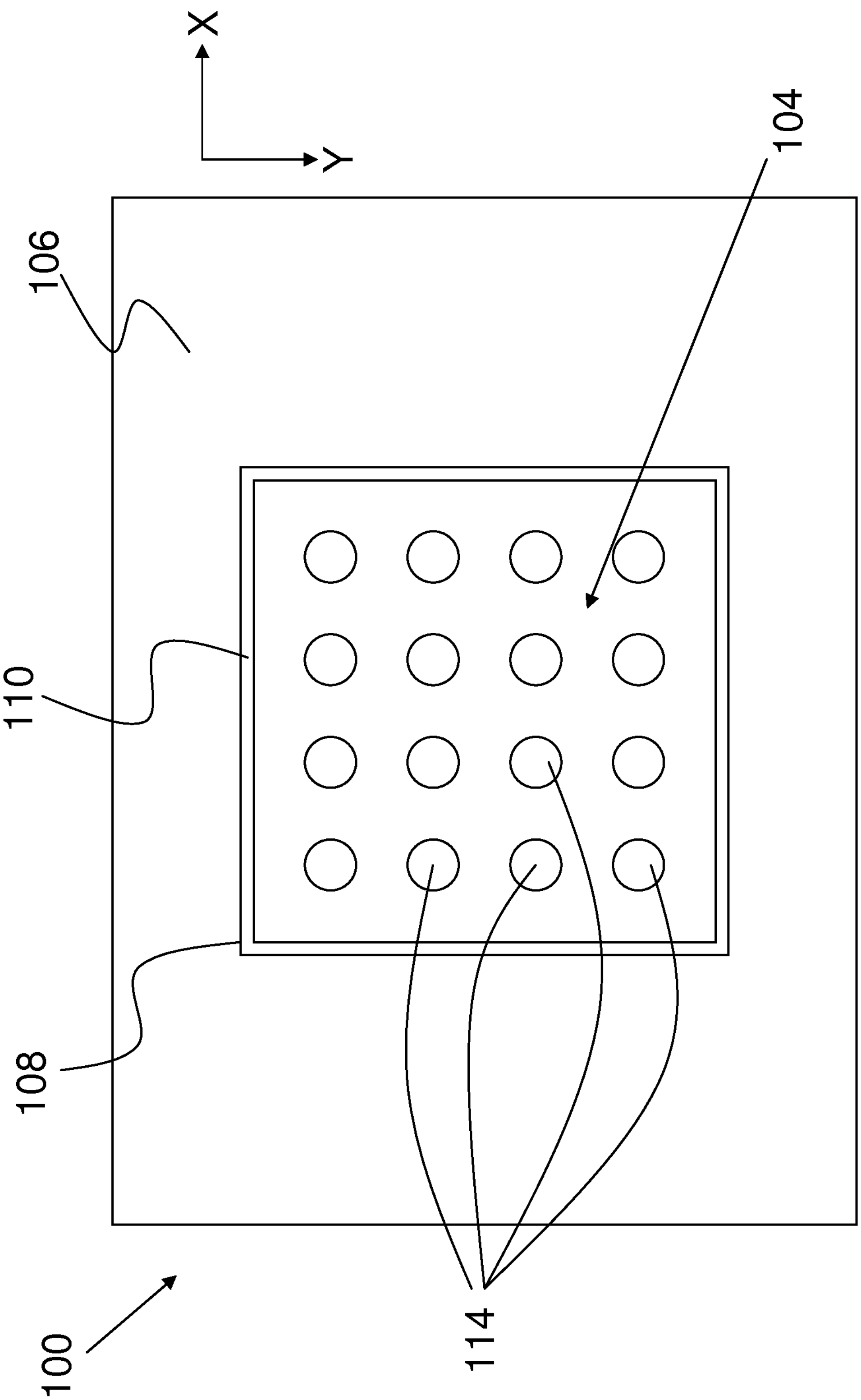

Fig. 4

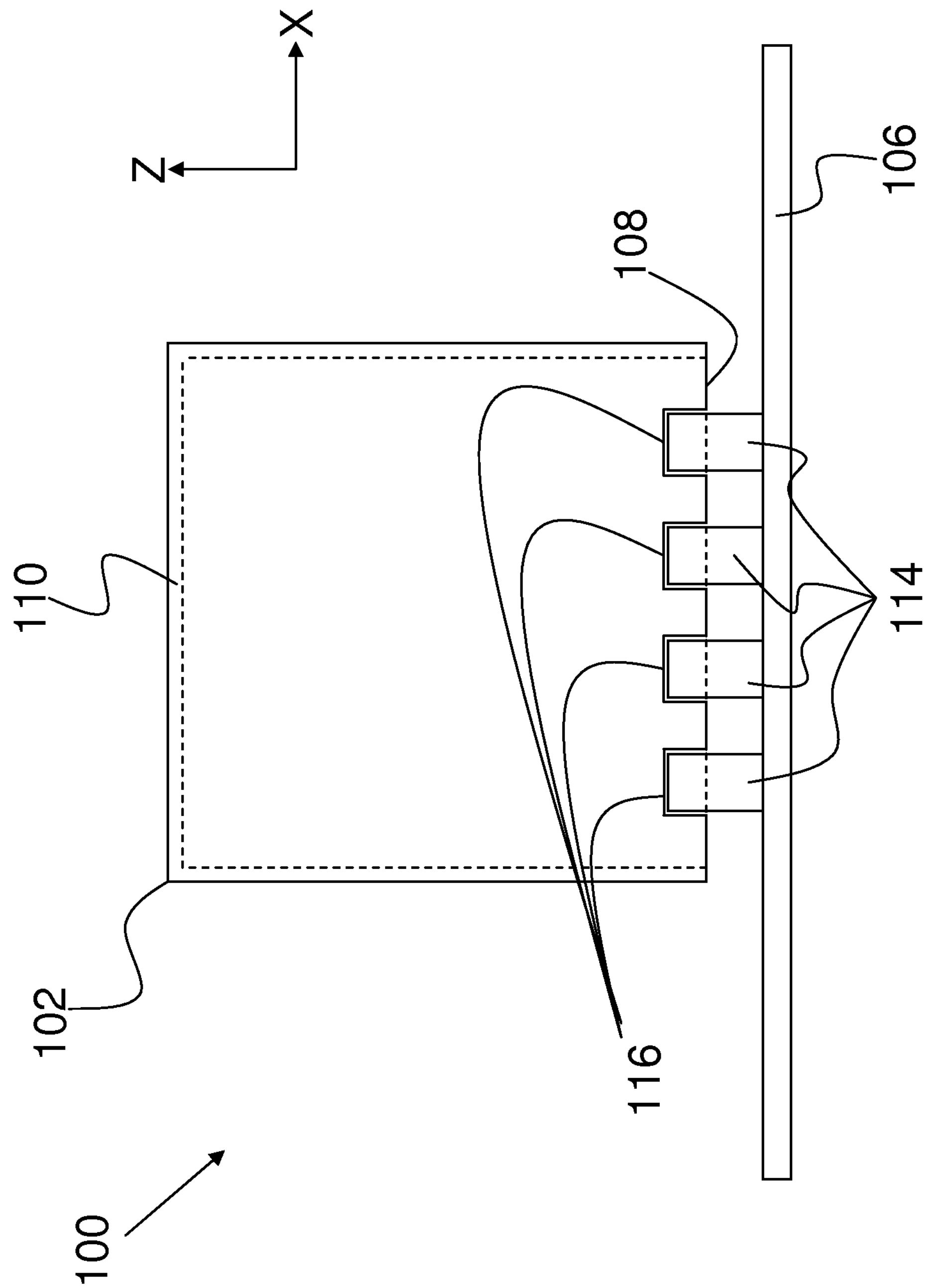

Fig. 5

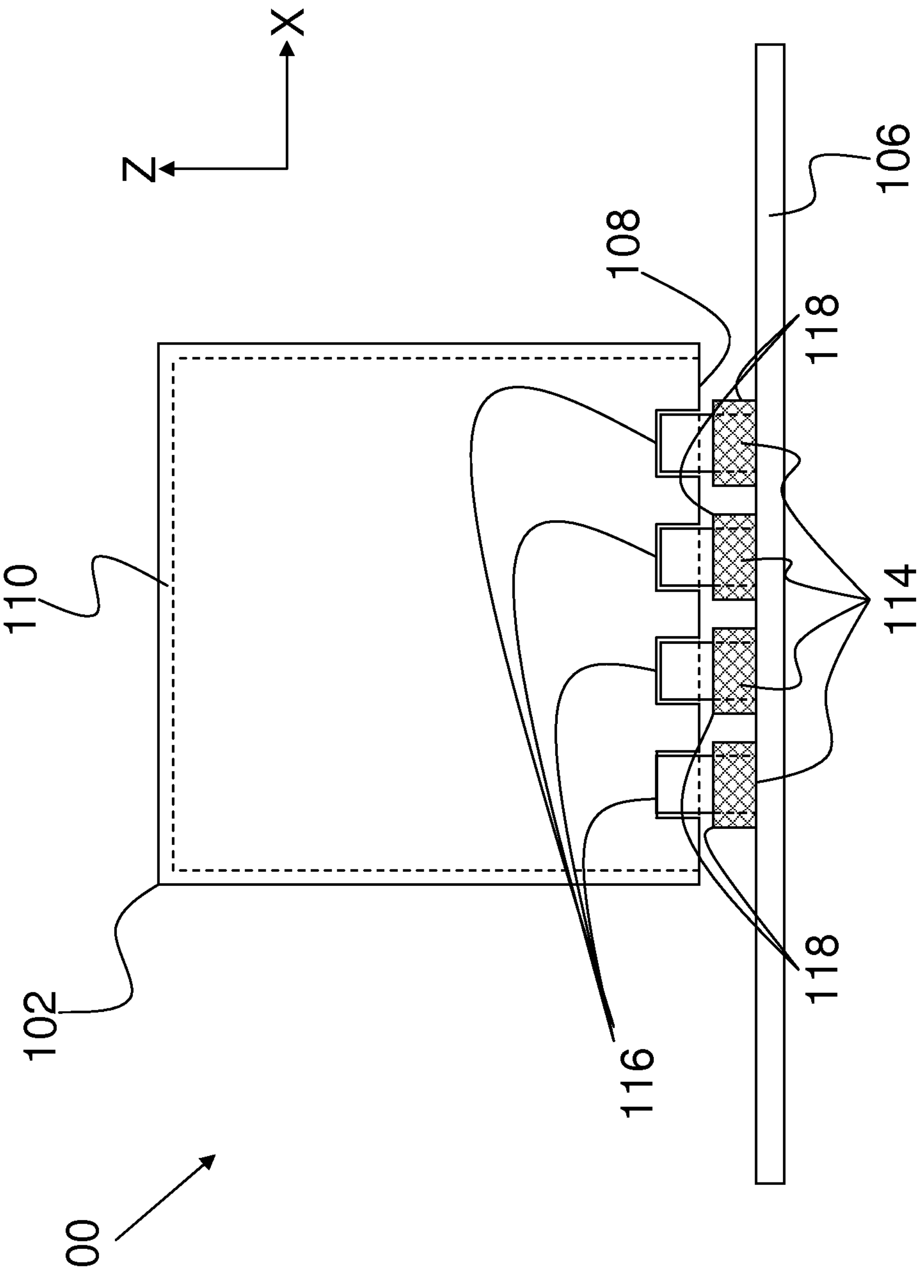

Fig. 6

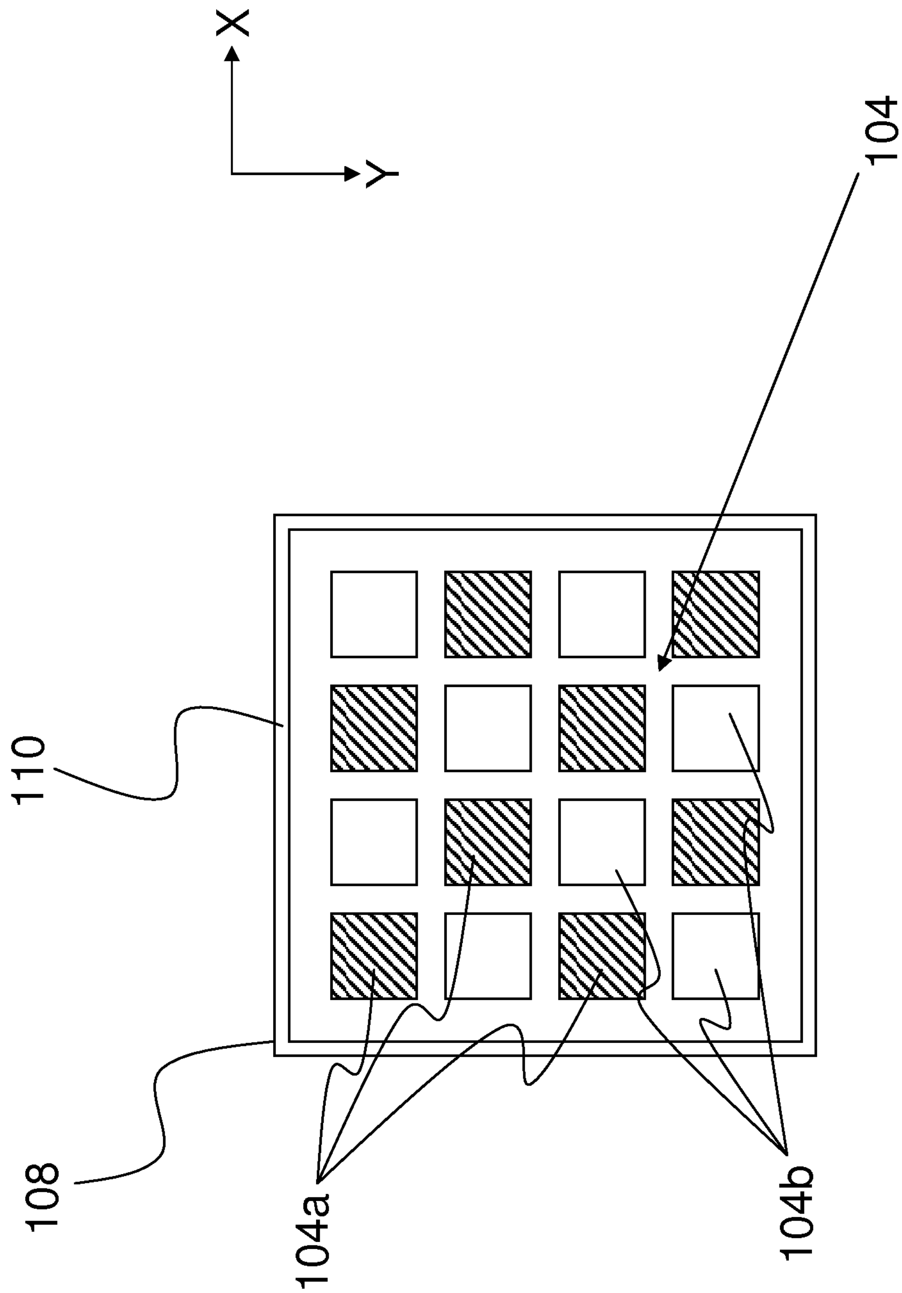

Fig. 7

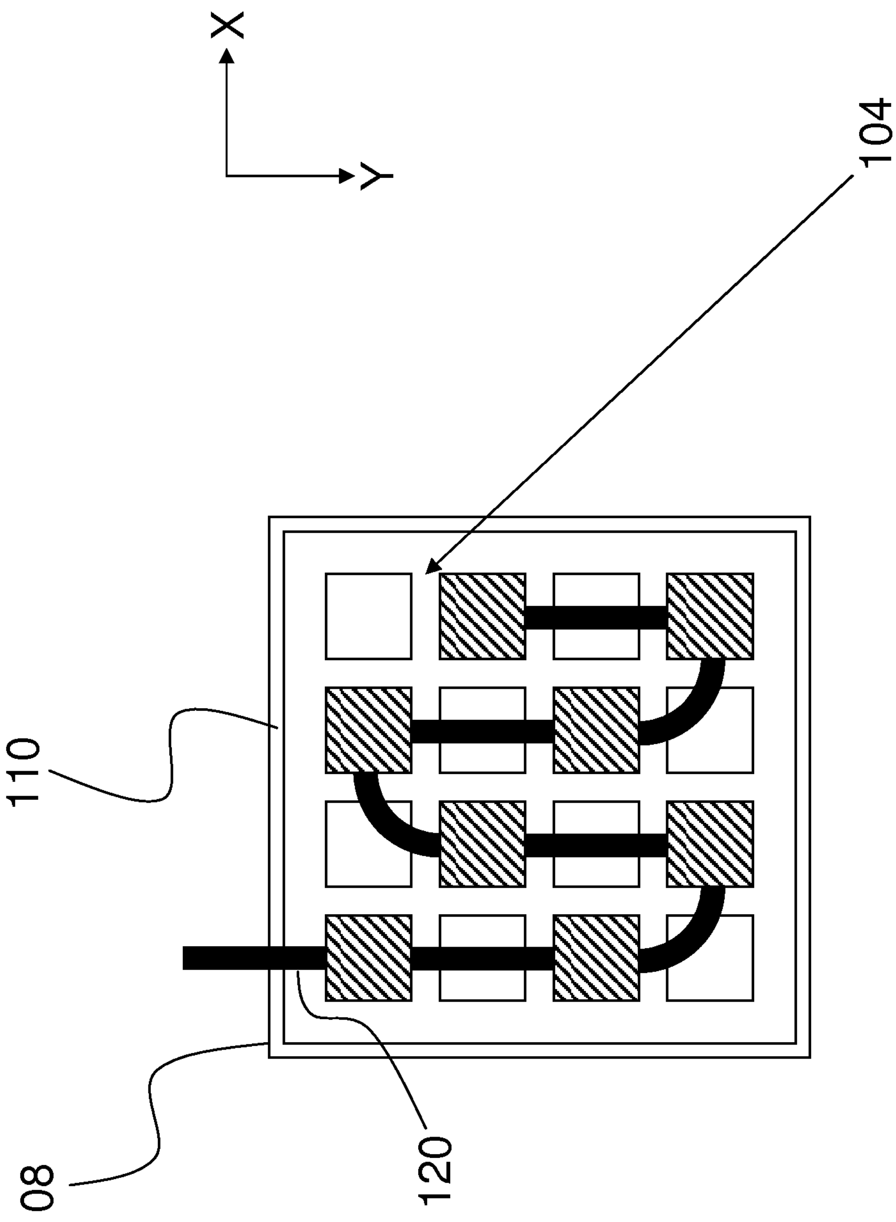

Fig. 8

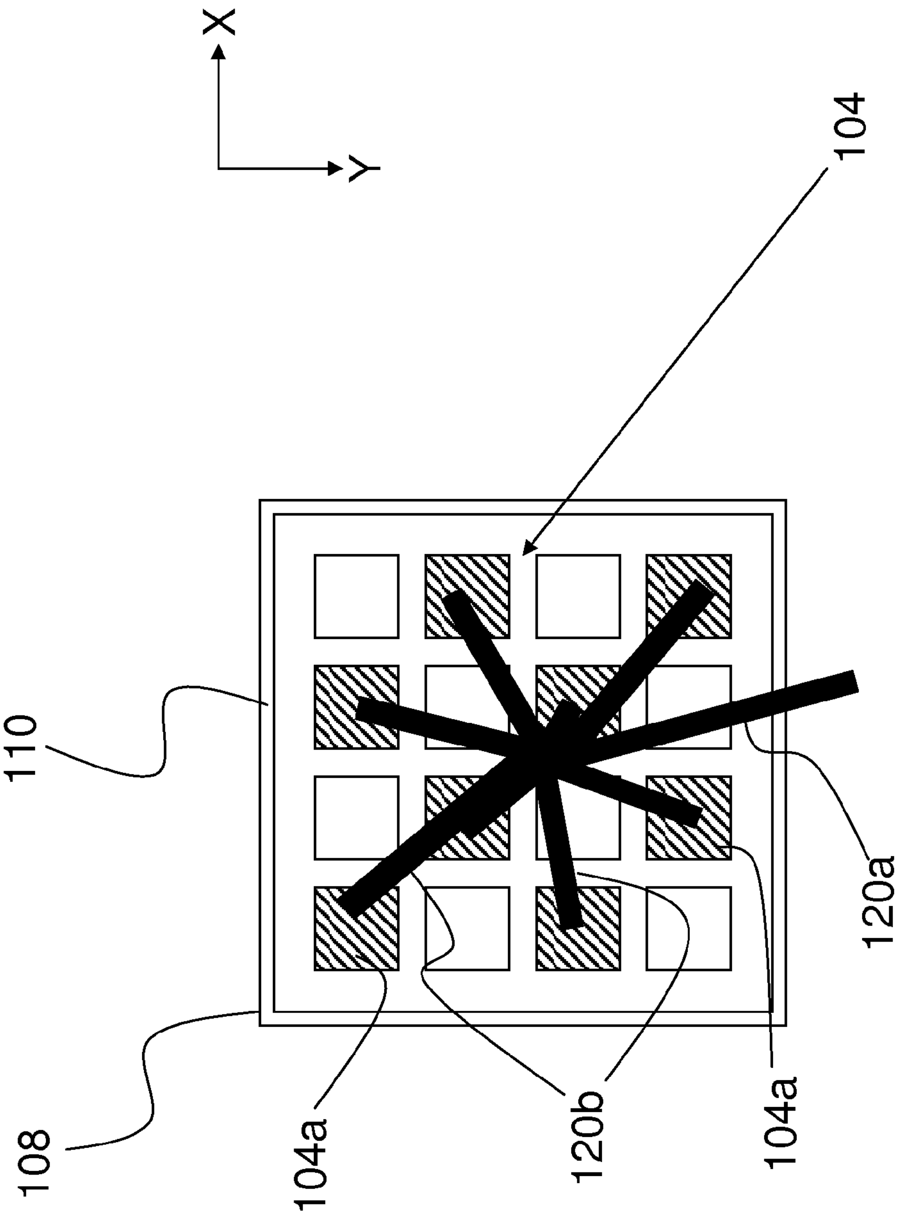

Fig. 9

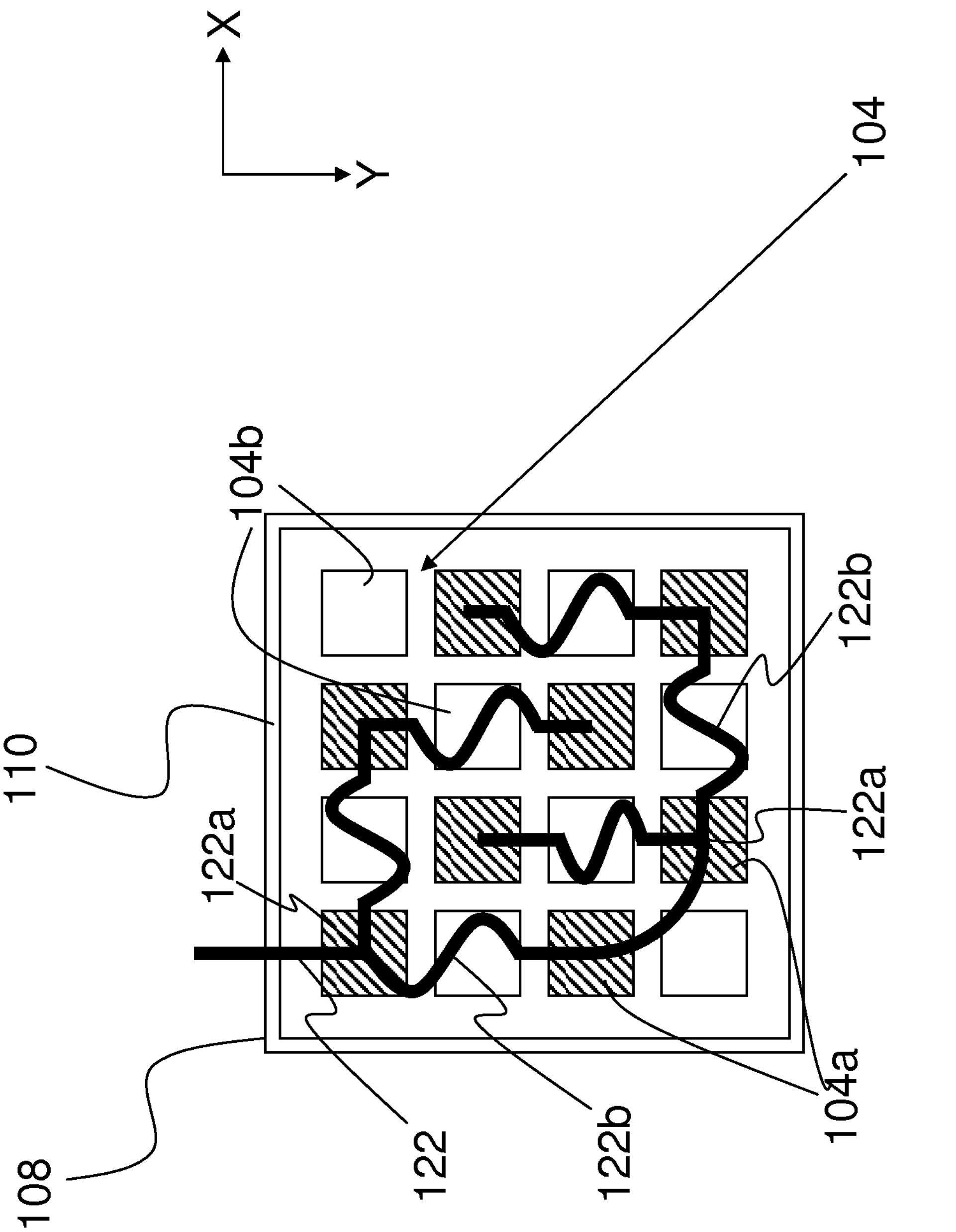

Fig. 10

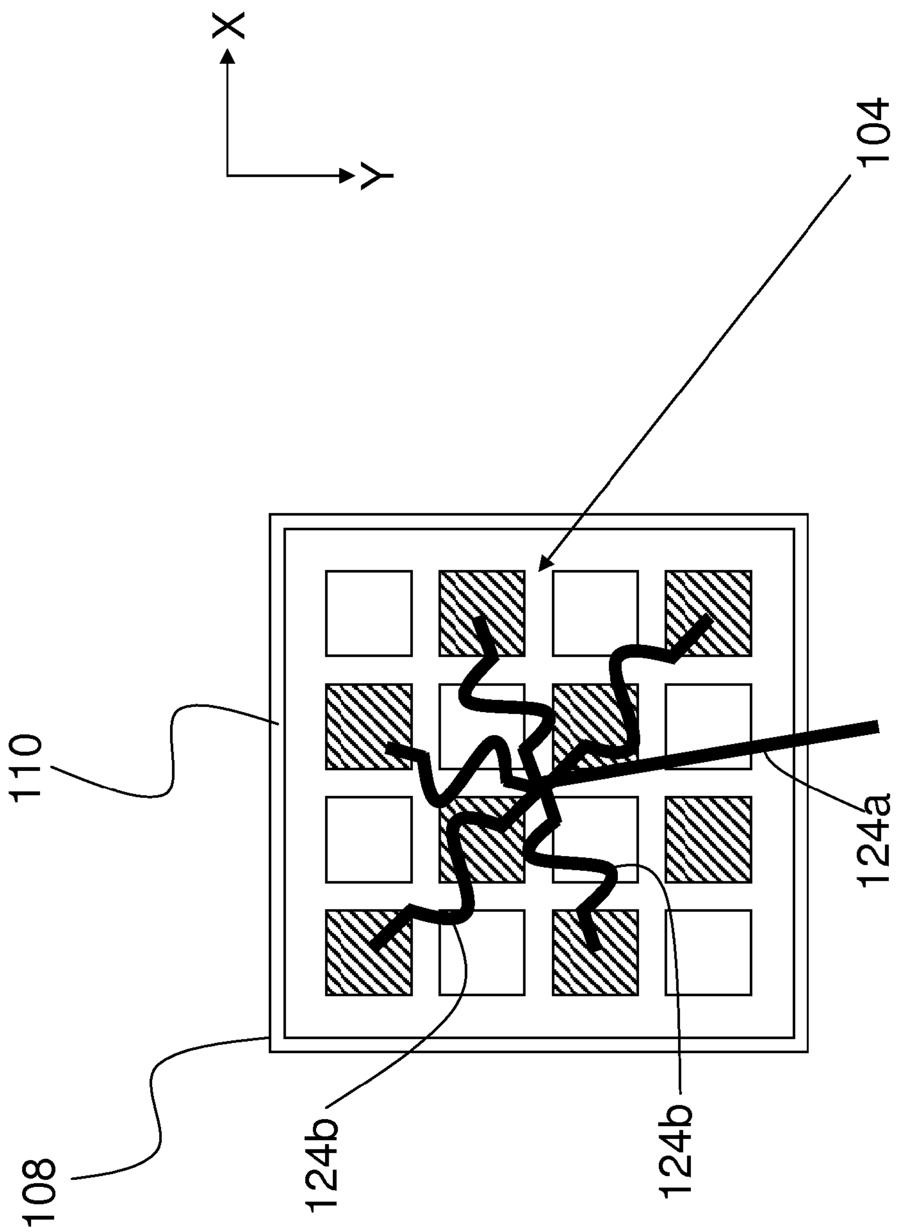

Fig. 11

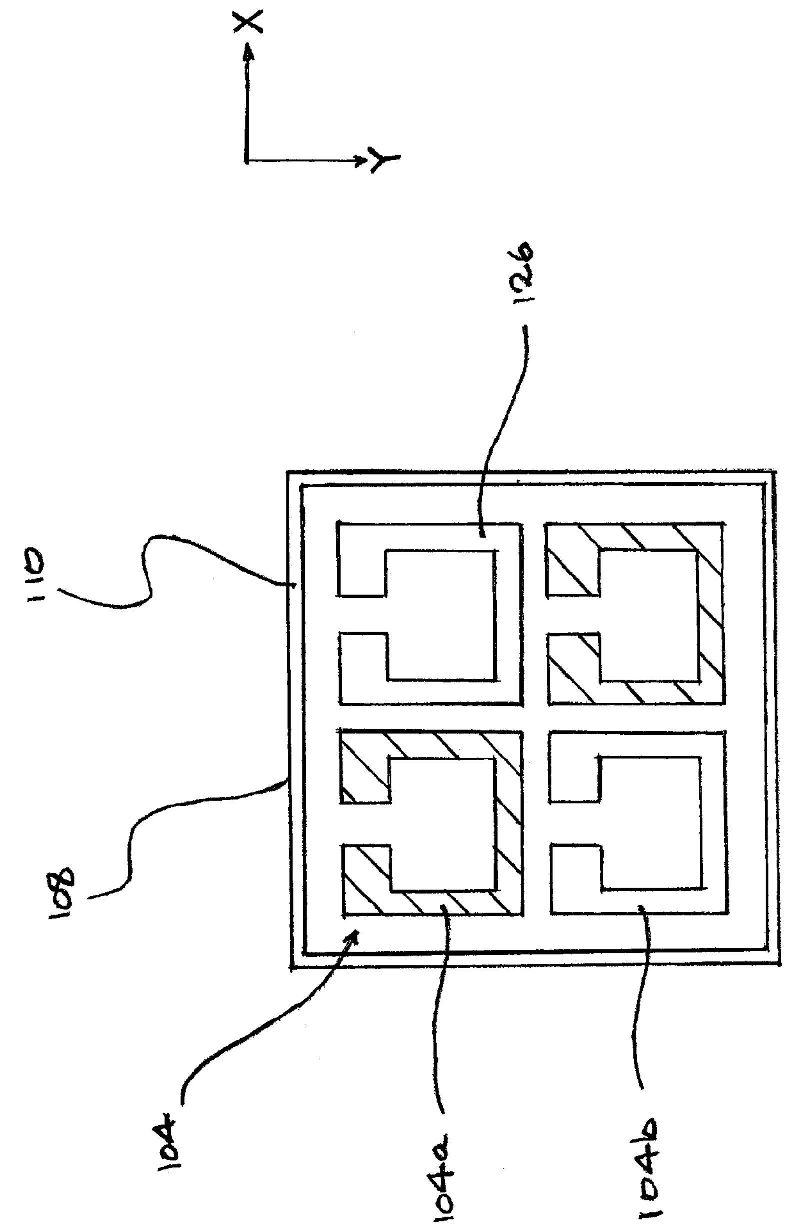

Fig. 12

FILTER

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is related to and claims the benefit of Australian Provisional Patent Application No. 2011903389, filed Aug. 23, 2011 and U.S. Provisional Patent Application No. 61/531,277, filed Sep. 6, 2011, both of whose disclosures are hereby incorporated by reference in their entirety into the present disclosure.

TECHNICAL FIELD

The present invention relates to filters, and in particular to a multi-mode filter including a resonator body for use, for example, in frequency division duplexers for telecommunication applications.

BACKGROUND

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that the prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

All physical filters essentially consist of a number of energy storing resonant structures, with paths for energy to flow between the various resonators and between the resonators and the input/output ports. The physical implementation of the resonators and the manner of their interconnections will vary from type to type, but the same basic concept applies to all. Such a filter can be described mathematically in terms of a network of resonators coupled together, although the mathematical topology does not have to match the topology of the real filter.

Conventional single-mode filters formed from dielectric resonators are known. Dielectric resonators have high-Q (low loss) characteristics which enable highly selective filters having a reduced size compared to cavity filters. These single-mode filters tend to be built as a cascade of separated physical dielectric resonators, with various couplings between them and to the ports. These resonators are easily identified as distinct physical objects, and the couplings tend also to be easily identified.

Single-mode filters of this type may include a network of discrete resonators formed from ceramic materials in a "puck" shape, where each resonator has a single dominant resonance frequency, or mode. These resonators are often coupled together by providing openings between cavities in which the resonators are located. Typically, the resonators provide transmission poles or "zeros", which can be tuned at particular frequencies to provide a desired filter response. A number of resonators will usually be required to achieve suitable filtering characteristics for commercial applications, resulting in filtering equipment of a relatively large size.

One example application of filters formed from dielectric resonators is in frequency division duplexers for microwave telecommunication applications. Duplexers have traditionally been provided at base stations at the bottom of antenna supporting towers, although a current trend for microwave telecommunication system design is to locate filtering and signal processing equipment at the top of the tower to thereby minimise cabling lengths and thus reduce signal losses. However, the size of single mode filters as described above can make these undesirable for implementation at the top of antenna towers.

Multi-mode filters implement several resonators in a single physical body, such that reductions in filter size can be obtained. As an example, a silvered dielectric body can resonate in many different modes. Each of these modes can act as one of the resonators in a filter. In order to provide a practical multi-mode filter it is necessary to couple the energy between the modes within the body, in contrast with the coupling between discrete objects in single mode filters, the latter of which is easier to control in practice.

The usual manner in which these multi-mode filters are implemented is to selectively couple the energy from an input port to a first one of the modes. The energy stored in the first mode is then coupled to different modes within the resonator by introducing specific defects into the shape of the body. In this manner, a multi-mode filter can be implemented as an effective cascade of resonators, in a similar way to conventional single mode filter implementations. Again, this technique results in transmission poles which can be tuned to provide a desired filter response.

An example of such an approach is described in U.S. Pat. No. 6,853,271, which is directed towards a triple-mode mono-body filter. Energy is coupled into a first mode of a dielectric-filled mono-body resonator, using a suitably configured input probe provided in a hole formed on a face of the resonator. The coupling between this first mode and two other modes of the resonator is accomplished by selectively providing corner cuts or slots on the resonator body.

This technique allows for substantial reductions in filter size because a triple-mode filter of this type represents the equivalent of a single-mode filter composed of three discrete single mode resonators. However, the approach used to couple energy into and out of the resonator, and between the modes within the resonator to provide the effective resonator cascade, requires the body to be of complicated shape, increasing manufacturing costs.

Two or more triple-mode filters may still need to be cascaded together to provide a filter assembly with suitable filtering characteristics. As described in U.S. Pat. Nos. 6,853,271 and 7,042,314 this may be achieved using a waveguide or aperture for providing coupling between two resonator mono-bodies. Another approach includes using a single-mode combline resonator coupled between two dielectric mono-bodies to form a hybrid filter assembly as described in U.S. Pat. No. 6,954,122. In any case the physical complexity and hence manufacturing costs are even further increased.

SUMMARY OF INVENTION

According to a first aspect a multi-mode cavity filter comprises a dielectric resonator body incorporating a piece of dielectric material, the piece of dielectric material having a shape such that it can support at least two substantially degenerate resonant modes; and a coupling structure comprising a plurality of independent coupling elements for coupling signals to the piece of dielectric material.

The plurality of coupling elements may be arranged in a substantially symmetrical array.

The independent coupling elements may be electrically isolated from one another.

Some of the plurality of coupling elements may be input elements arranged to deliver signals to the piece of dielectric material, and others of the plurality of coupling elements may be output elements arranged to recover signals from the piece of dielectric material. At least one input element may be coupled to at least one output element.

The piece of dielectric material may comprise at least two faces, the input elements being arranged on a first of the at least two faces, and the output elements being arranged on a second of the at least two faces. Alternatively, the input and output elements may be arranged on a single face.

At least some of the plurality of coupling elements may be patches formed on a surface of the piece of dielectric material. Some of the patches may be of a regular geometric shape, and some of the patches may be of an irregular geometric shape.

Alternatively or additionally, at least some of the plurality of coupling elements may be probes arranged to abut a surface of, or at least partially penetrate a surface of, the piece of dielectric material. The probes may have a substantially circular cross section. A shielding element may be associated with each probe.

At least some of the plurality of coupling elements may be magnetic field generating elements. The magnetic field generating elements may be loop elements.

The plurality of coupling elements may comprise at least a first set of coupling elements configured to couple a first signal to the piece of dielectric material for exciting a first resonant mode of the dielectric resonator, and a second set of coupling elements configured to couple a second signal to the piece of dielectric material for exciting a second resonant mode of the dielectric resonator.

At least some of the plurality of coupling elements may be connected to each other in series.

The multi-mode cavity filter may further comprise a primary transmission line configured to transmit signals to a plurality of secondary transmission lines branching off the primary transmission line, wherein each of the plurality of secondary transmission lines is configured to feed a signal to a single coupling element.

According to a second aspect, a method of manufacturing a multi-mode cavity filter comprises: providing a resonator body of dielectric material capable of supporting at least two substantially degenerate resonant modes, and providing a coupling structure comprising a plurality of coupling elements for coupling signals to the piece of dielectric material.

According to another embodiment, a multi-mode cavity filter may comprise a dielectric resonator body incorporating a piece of dielectric material, the piece of dielectric material having a shape such that it can support at least two substantially degenerate resonant modes; and a phased array of coupling elements for coupling signals to the piece of dielectric material.

The multi-mode cavity filter may further comprise a signal transmission line for transmitting a signal to at least one of the plurality of the coupling elements. The phase of the signal at a particular coupling element along the transmission line may be determined by the position of that coupling element along the transmission line.

The transmission line may include at least one meander.

The or each coupling element may be positioned at a predetermined distance along the transmission line such that the signal reaching the or each coupling element has a predetermined phase.

At least some of the plurality of coupling elements may be connected to each other in series.

The phased array of coupling elements may comprise a primary transmission line configured to feed signals to plurality of secondary transmission lines branching off the primary transmission line, wherein each of the plurality of secondary transmission lines is configured to transmit a signal to at least one coupling element.

The multi-mode cavity filter may further comprise an amplitude determination mechanism for determining the amplitude of a signal transmitted along the transmission line. The relative amplitudes of signals transmitted to each of the coupling elements may be predetermined.

According to another embodiment, a method of manufacturing a multi-mode cavity filter may comprise: providing a resonator body of dielectric material capable of supporting at least two substantially degenerate resonant modes; and providing a phased array of coupling elements for coupling signals to the piece of dielectric material.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the following drawings, in which:

FIG. **1** is a schematic perspective view of an example of a multi-mode filter;

FIG. **2** is a schematic underside view of the multi-mode filter of FIG. **1**;

FIG. **3** is a schematic side view of a further example of a multi-mode filter;

FIG. **4** is a schematic underside view of the multi-mode filter of FIG. **3**;

FIG. **5** is a schematic side view of a further example of the multi-mode filter of FIG. **3**;

FIG. **6** is a schematic side view of a further example of the multi-mode filter of FIG. **5**;

FIG. **7** is a schematic underside view of a further example of a multi-mode filter;

FIGS. **8** to **11** are schematic underside views of further examples of the multi-mode filter of FIG. **7**; and

FIG. **12** is a schematic underside view of an example of a multi-mode filter having coupling elements in the form of loop elements.

DETAILED DESCRIPTION

An example of a multi-mode filter will now be described with reference to the drawings.

FIG. **1** shows a filter **100** having a resonator body **102** which is coupled by a coupling structure **104** (not shown in FIG. **1**) to a substrate **106**. The coupling structure **104** is located on a surface of the resonator body **102** that is adjacent to the substrate **106**. The substrate **106** and the coupling structure **104** will be discussed in further detail below. The resonator body **102** is formed from a piece of dielectric material having suitable dielectric properties. In one example, the resonator body **102** is a ceramic material, although this is not essential and alternative materials can be used. Additionally, the body **102** can be a multilayered body including, for example, layers of materials having different dielectric properties. In one example, the body **102** can include a core of a dielectric material, and one or more outer layers of different dielectric materials.

The coupling structure **104** provides coupling to a plurality of the resonance modes of the resonator body. In use, a radio frequency signal, containing, say, frequencies from within the 1 MHz to 100 GHz range, can be supplied to or received from the coupling structure **104**. In a suitable configuration, this allows a signal to be filtered to be supplied to the resonator body **102** for filtering, or can allow a filtered signal to be obtained from the resonator body, as will be described in more detail below.

The use of an electrically conductive coupling structure formed from an array of individual elements electrically independent from one another allows the signal to be coupled to a plurality of resonance modes of the resonator body **102**. This allows a more simplified configuration of resonator body **102** and coupling structure **104** to be used as compared to traditional arrangements. For example, this avoids the need to have a resonator body including cut-outs or other complicated shapes, as well as avoiding the need for coupling structures that extend into the resonator body. This, in turn, makes the filter cheaper and simpler to manufacture, and can provide enhanced filtering characteristics. In addition, the filter is small in size, typically of the order of 6000 mm^3 per resonator body, making the filter apparatus suitable for use at the top of antenna towers. It will be appreciated by those skilled in the art that, while the individual coupling elements are electrically independent from one another, there will inevitably be some degree of mutual coupling between some couplings which will need to be taken into account in the design of the filter. This mutual coupling is, however, incidental, and not an intended part of the operation of the invention.

A number of further features will now be described.

The resonator body **102** usually includes an external coating (FIG. **2**; **110**) of conductive material, such as silver, although other materials could be used such as gold, copper, or the like. The conductive material may be applied to one or more surfaces of the body. A region of the surface adjacent the coupling structure **104**, that is the surface at which the resonator body **102** is coupled to the substrate **106**, may be uncoated to allow coupling of signals to the resonator body.

The resonator body **102** can be any shape, but generally defines at least two orthogonal axes. In the current example, the resonator body **102** is a cuboid body, and therefore defines three orthogonal axes substantially aligned with surfaces of the resonator body, as shown by the axes X, Y, Z. As a result, the resonator body **102** has three dominant resonance modes that are substantially orthogonal and substantially aligned with the three orthogonal axes.

Cuboid structures are particularly advantageous as they can be easily and cheaply manufactured, and can also be easily fitted together, for example by arranging multiple resonator bodies in contact. Cuboid structures typically have clearly defined resonance modes, making configuration of the coupling structure more straightforward. Additionally, the use of a cuboid structure provides a planar surface so that the coupling structure can be arranged in a single plane parallel to the planar surface. This can help maximise coupling between the couplings and resonator body **102**, as well as allowing the coupling structure **104** to be more easily manufactured.

For example, the couplings may be provided on the substrate **106**. In this instance, the provision of a planar surface **108** allows the substrate **106** to be a planar substrate, such as a printed circuit board (PCB) or the like. However, alternative arrangements can be used, such as coating the coupling structure **104** onto the resonator body directly.

In use, resonance modes of the resonator body provide respective energy paths between the input and output. Furthermore, the input coupling and the output coupling can be configured to allow coupling therebetween to provide an energy path separate to energy paths provided by the resonance modes of the resonator body. This can provide four parallel energy paths between the input and the output. These energy paths can be arranged to introduce at least one transmission zero to the frequency response of the filter, as will be described in more detail below. In this regard, the term "zero" refers to a transmission minimum in the frequency response of the filter, meaning transmission of signals at that frequency will be minimal, as will be understood by persons skilled in the art.

A specific example filter is shown in FIG. **2**. In this example, the filter **100** includes a resonator body **102** having a surface **108** at which the body is coupled to the substrate **106**. A coating **110** of conductive material (such as metal) is formed around the periphery of the surface **108**. The coating **110** may be formed on at least one of the other faces of the resonator body **102**. In some embodiments, all of the other faces of the resonator body **102** are at least partially coated by the coating **110**. However, as noted above, the surface **108** of the body adjacent the substrate **106** is left substantially uncoated to allow signals to be coupled to the resonator body **102**, with the remainder of the surface, which is coated, being electrically connected to the groundplane located on, or within the substrate.

The coupling structure **104** of this embodiment is formed from an array of mutually insulated pads or patches **112** via which signals are transmitted to and/or recovered from the resonator body **102**. The mutual insulation of each patch keeps the interference of signals between the patches to a minimum. In the embodiment shown in FIG. **2**, the coupling structure **104** includes an array of sixteen substantially square patches **112** arranged in a 4 by 4 configuration. The patches **112** are configured to couple to a track or to connectors on the substrate **106**. As an alternative to being connected directly to the substrate **106**, in other embodiments, the patches **112** may be connected to a printed circuit board (not shown) via which signals are fed to the resonator body **102**.

Each of the patches **112** includes at least one connection, or feed point (not shown), to which a feed line (not shown) can be connected for provision of a signal to the patch. In some embodiments, each patch **112** includes two or more feed points. Similarly, in some embodiments, the or each feed point is located centrally within the patch **112** whereas, in other embodiments, the or each feed point is located offset from the centre of the patch.

Although, in this embodiment, each of the patches **112** has a square shape, the patches can be any shape. In some embodiments, the patches **112** are compact shapes such as circles, triangles, squares, pentagons and the like. In other embodiments, the patches **112** are elongated shapes such as rectangles, ellipses and the like. Similarly, while, in this embodiment, all of the patches **112** are the same shape, in other embodiments, a combination of patches of different compact geometric shapes, or a combination of patches of compact and elongated geometric shapes may be used. Patches **112** of compact geometric shapes have greater rotational symmetry than patches of elongated geometric shapes and, consequently, compact geometric shaped patches couple predominantly to the electric field (E-field), with relatively little coupling to the magnetic field (H-field). In contrast, patches having elongated geometric shapes couple to a greater degree to the H-field in addition to the E-field coupling.

In addition to the shape of the patches **112**, the size of the patches is also determinative with regard to the strength with which the patches couple to the E-field and to the H-field. Relatively small patches couple primarily to the E-field. Relatively large patches contribute an amount of H-field coupling in addition to the E-field coupling. It will be appreciated that a combination of patches of different sizes may be used to achieve a desired coupling to the E-field and the H-field.

Another factor that determines the amount by which the patches **112** contribute to the E-field and the H-field is the position of the feed point (the signal input point) into each patch. If the point at which a signal is fed into a patch **112** is substantially central in the patch, then the predominant excitation provided by the patch is an E-field excitation. However, if the signal is fed into the patch at a point offset from the centre, then H-field excitation is generated in addition to an E-field excitation.

FIGS. **3** and **4** show a side view and an underside view respectively of an alternative embodiment of the invention in which the coupling structure **104** is formed from an array of probe-like connections **114**. Each of the probes **114** is an elongate conductor which is configured to couple, at one end, to a track or to connectors on the substrate **106**, and at the other end, to the surface **108** of the resonator body **102**. In this embodiment, the probes **114** are substantially circular in cross section. However, probes having other cross sections, such as square or elliptical, may be used in alternative embodiments. A number of connections, such as a connection between the metallic coating **110** and a track or ground-plane layer on the substrate **106**, have been omitted from FIG. **3** (and FIGS. **5** and **6**) for clarity. Those skilled in the art will appreciate, however, that the filter **100** may include further connections and components not essential to the understanding of this invention and which have been omitted from the drawings.

As with the embodiments described above in which the coupling structure **104** includes patches **112**, the probes **114** may be arranged in a regular array, for example in a 4 by 4 configuration. Alternatively, a smaller or larger array may be used, and/or the probes may be arranged in an irregular configuration.

In FIG. **5**, the resonator body **102** is shown having a coupling structure **104** which includes an array of probes **114** which penetrate the surface **108** of the resonator body. Each probe **114** is configured to fit into one of an array of complementary-shaped recesses **116** formed in the resonator body **102**. In some embodiments, the probes **114** penetrate a short depth into the resonator body **102**. In other embodiments, the probes **114** penetrate a substantial proportion of their length into the resonator body **102**. The lengths of the probes **114** has an effect on the degree of coupling afforded from the probe to the resonator body **102**. Thus, the lengths of the probes can be chosen according to the coupling required at each probe **114**. In some embodiments, some probes **114** in an array can have lengths that differ from other probes in the array, thereby creating a desired field pattern to excite particular modes within the resonator body **102**.

FIG. **6** shows an alternative embodiment of the invention in which each of the probes **114** includes a shielding element **118**. Each shielding element **118** is a grounded conductor which at least partially surrounds a corresponding probe **114**. The shielding elements **118** are configured and positioned such that they are in contact with the metallic coating **110** surrounding the resonator body **102**, and may take any known form, such as a wire mesh ring or a solid shield. In some embodiments, where the probes **114** are shorter than a particular length, shielding elements **118** are not required and may, therefore, be omitted.

The degree of coupling of the signal from each probe **114** to a resonance mode of the resonator body **102** is, in part, determined by the length of the probe. The length of each probe **114** also has an effect on the degree of H-field coupling relative to the E-field coupling from the probe. Additionally, the amount by which a probe **114** penetrates into the resonator body **102** affects the degree of coupling from the probe. A relatively long probe which penetrates relatively deeply into the resonator body **102** generates a greater H-field coupling than a relatively shorter probe, or a probe that penetrates a shorter depth into the resonator body **102**. A relatively very short probe **114** contributes little or no H-field coupling. What constitutes 'long' and 'short' in terms of probe length depends on the degree of penetration of the probe into the resonator body **102**: a short probe is one which has minimal penetration into the body, and a long probe is one which penetrates the body to a significant degree.

So far, two alternatives for the elements of the coupling structure have been described—patches **112** and probes **114**. In an alternative embodiment, the coupling structure **104** includes an array of loop elements (not shown), which may be arranged in a configuration similar to those described above. The loop elements serve to couple substantially to the H-field, with relatively little E-field coupling occurring.

It will be apparent to those skilled in the art that, in alternative embodiments, a combination of patches **112**, probes **114** and loop elements might be implemented in order to achieve a desired field pattern and to achieve a desired level of excitation of particular modes within the resonator body **102**.

So far, in the above examples, nothing has been said regarding the functions of the individual elements of the coupling structure **104**. FIG. **7** shows an embodiment in which the coupling structure **104** includes two types of couplings: input couplings **104***a* (shown with hatching), and output couplings **104***b* (shown without hatching). In this instance, a signal supplied via one of the inputs **104***a* couples to the resonance modes of the resonator body **102**, so that a filtered signal is obtained via the outputs **104***b*. While, in this example, half of the coupling elements are inputs **104***a* and half of the coupling elements are outputs **104***b*, it will be appreciated that this arrangement is for the purpose of example only, and fewer or more input and/or output couplings may be used depending on the preferred implementation. Moreover, the arrangement of inputs and outputs on the resonator body **102** may be varied as described below.

In one example, different coupling structures can be provided on different surfaces of the resonator body. A further alternative is for a coupling structure to extend over multiple surfaces of the resonator body, with different coupling elements being provided on different surfaces (for example, an array of input couplings on one surface of the resonator body **102** and an array of output couplings on a different surface of the resonator body), or with coupling elements extending over multiple surfaces. Such arrangements can be used to allow a particular configuration of input and output to be accommodated, for example to meet physical constraints associated with other equipment, or to allow alternative coupling arrangements to be provided. In use, a configuration of the input and output coupling elements, along with the configuration of the resonator body **102** controls a degree of coupling with each of the plurality of resonance modes and hence the properties of the filter, such as the frequency response.

In addition to couplings for feeding signals to and from the resonator body **102**, in some examples of the invention, one or more of the inputs are coupled to one or more of the outputs and vice versa.

As has already been discussed, signals are fed to each of the patches **112** and probes **114** via one or more transmission or feed lines. The feed lines may take the form, for example, of a track on a PCB. In some examples of the invention, such as in the example shown in FIG. **8**, a feed line **120** is connected to a plurality of coupling elements **104***a* in series. In this example, the feed line **120** is coupled only to the input coupling elements **104***a*. However, in other embodiments, the feed line may be coupled to more or fewer coupling elements **112**, **114**. The meandering nature of the feed line **120** allows a designer of the filter **100** to select which coupling elements the feed line is connected to, and the order in which they are connected. Furthermore, as will be discussed further below, the length of the feed line can be selected such that the signal arriving at any particular coupling element has a desired phase.

In the example shown in FIG. **9**, the coupling elements **104***a* receive signals via an alternative feed line **120**. In this example, a primary feed line **120***a* transmits signals to a plurality of secondary feed lines **120***b* which, in turn, transmit signals to the coupling elements **104***a*. The structure of the primary and secondary feed lines in this example resemble a “star” or “spider” arrangement.

The impedance of the feed lines is another factor that affects the degree of coupling of the signal to the resonance modes in the resonator body **102**.

As is mentioned briefly above, the degree of coupling, and the particular resonance mode to which a coupling is made can be determined, in part, by the phase of a signal at a particular coupling element. FIGS. **8** and **9** show alternative arrangements of feed or transmission lines **120** that transmit signals from a signal source (not shown) to one or more of the coupling elements of the coupling structure **104**. The length of the feed line along which a signal is transmitted affects the phase of the signal when it arrives at a coupling element. That is to say, a first signal that travels comparatively greater distance along a feed line to a coupling element will be at least partially out of phase with a second signal that travels a comparatively shorter distance along a feed line. Of course, if the extra distance traveled by a first signal is equal to one complete cycle of the that signal, then the first and second signals would be in phase with one another.

The relative phases of signals at the coupling elements can be dictated by configuring the length of the feed line along which the signals are transmitted. By dictating the phase of the signals at each coupling element, it is possible to control higher-order spurious modes and, preferably, reduce their amplitude. By reducing the amplitude of the spurious higher-order modes, filter designers are able to meet demanding filter specifications without the need to make significant, complex and expensive structural modifications to the dielectric material or the need to provide additional filtering stages to attenuate the unwanted responses.

FIG. **10** shows an underside view of the resonator body **102** with a plurality of input couplings **104***a* and a plurality of output couplings **104***b*. In this example, a feed line **122** provides a connection between all of the input couplings **104***a*. In contrast to the examples shown in FIGS. **8** and **9**, the feed line **122** of FIG. **10** includes a number of junctions **122***a* which allow the feed line to be directed to desired coupling elements on the resonator body **102**. In addition, the feed line **122** includes a number of meanders **122***b* which serve to increase the length of the feed line between coupling elements on the line. As discussed above, the distance that a signal travels along a feed line dictates, in part, the phase of the signal at a coupling element. Therefore, it is possible to achieve a phase of a signal at a particular coupling element by designing the feed line such that the signal travels an appropriate distance along the feed line to reach the coupling element. Of course, it will be apparent to those skilled in the art that, while the feed line is shown to meander in this invention, other mechanisms for increasing the length of the feed line could alternatively be used. Similarly, the feed line may comprise a single continuous feed line with no junctions, and incorporating fewer or more meanders or similar mechanisms for increasing the length of the feed line between coupling elements. Alternatively, the feed line arrangement may be similar to the arrangement shown in FIG. **9**, with meanders being incorporated into the secondary feed lines **120***b*. An example of such an arrangement is shown in FIG. **11**. A primary feed line **124***a* transmits signals to a plurality of secondary feed lines **124***b*, each of which is coupled to a coupling element. While, in this example, only five secondary feed lines **124***b* are shown, in practice, any number of secondary feed lines may be incorporated, connecting the primary feed line **124***a* to any number of coupling elements, as required by the design of the filter.

In practice, the length of the feed line **122** feeding each coupling element is calculated, based on the desired phase at each coupling element, using an electromagnetic simulation tool, such as CST Microwave Studio, manufactured by Computer Simulation Technology AG.

FIG. **12** is a schematic underside view of an example of a multi-mode filter having a coupling structure **104** in the form of an array of loop elements. The input couplings **104***a* are shown with hatching, and the output couplings are shown without hatching. A plurality of each kind is shown.

In some examples of the invention, a concept known as amplitude tapering may be used to control and specify the amplitude across the array of coupling elements. In one scenario, the amplitude of the signal transmitted to coupling elements at the centre of the array is greater than the amplitude of the signal or signals transmitted to coupling elements surrounding the central element, and the coupling elements around the periphery of the array. This concept is advantageous in targeting the excitation predominantly to a specific mode, for example, in the case of an array of patches, this mechanism would target a known mode such as the TM110 mode.

In an alternative scenario, the amplitude of the signal transmitted to coupling elements at the centre of the array is lower than the amplitude of the signal or signals transmitted to coupling elements surrounding the central element, and the coupling elements around the periphery of the array. This concept is advantageous as a means to minimise mutual coupling between a group of input elements on one side of the array (and hence resonator body) and output elements on the other side.

An advantage of the above-described examples is that, by controlling particular design aspects of the filter, such as the size, shape and location of the coupling elements, and the length and other aspects of the transmission line feeding signals to the coupling elements, it is possible to accurately control the fields generated as a result of the signal and, thus, the excitation modes of the resonator body that are excited by the signals.

In the examples described above, a cuboid resonator body **102** is used. Such a resonator body enables coupling of up to three resonance modes. However, as will be apparent to those skilled in the art, a resonator body of a different three-dimensional shape may provide a different number of degenerate resonance modes. For example, a rectangular cuboid resonator body (that is a 2:2:1 ratio cuboid) has four degenerate resonance modes. Thus, filters can be designed having one or more resonator bodies or the same or different shapes, depending on the required characteristics of the filter.

Moreover, characteristics of a filter may be chosen by applying defects to the resonator body. Such defects may include shaving a particular amount of dielectric material from an edge of the resonator body, or drilling one or more holes of a particular size into the body.

In some scenarios, a single resonator body cannot provide adequate performance (for example, attenuation of out of band signals). In this instance, filter performance can be improved by providing two or more resonator bodies arranged in series, to thereby implement a higher-performance filter.

In one example, this can be achieved by providing two resonator bodies in contact with each other, with one or more apertures provided in the silver coatings of the resonator bodies, where the bodies are in contact. This allows the fields in each cube to enter the adjacent cube, so that a resonator body can receive a signal from or provide a signal to another resonator body. When two resonator bodies are connected, this allows each resonator body to include only a single coupling array, with a coupling array on one resonator body acting as an input and the coupling array on the other resonator body acting as an output. Alternatively, the input of a downstream filter can be coupled to the output of an upstream filter using a suitable connection such as a short transmission line.

The above described examples have focused on coupling to up to four modes. It will be appreciated this allows coupling to be to low order resonance modes of the resonator body. However, this is not essential, and additionally or alternatively coupling could be to higher order resonance modes of the resonator body.

Persons skilled in the art will appreciate that numerous variations and modifications will become apparent. All such variations and modifications which become apparent to persons skilled in the art are considered to fall within the spirit and scope of the invention broadly appearing before described.

The invention claimed is:

1. A multi-mode cavity filter comprising:

a dielectric resonator body incorporating a piece of dielectric material, the piece of dielectric material having a shape supporting at least two substantially degenerate resonant modes and one face having a surface; and

a coupling structure on said surface of said one face, said coupling structure including a first plurality of independent coupling elements arranged to couple input signals into the piece of dielectric material and a second plurality of independent coupling elements arranged to recover output signals from the piece of dielectric material, wherein the first plurality of independent coupling elements is distinct from the second plurality of independent coupling elements.

2. The multi-mode cavity filter according to claim **1**, wherein the first and second pluralities of coupling elements are arranged in a substantially symmetrical array.

3. The multi-mode cavity filter according to claim **1**, wherein the independent coupling elements are electrically isolated from one another.

4. The multi-mode cavity filter according to claim **1**, wherein at least some of the first and second pluralities of coupling elements are probes arranged to penetrate said surface of the piece of dielectric material.

5. A multi-mode cavity filter according to claim **1**, wherein at least one of the first plurality of independent coupling elements is coupled to at least one of the second plurality of independent coupling elements.

6. The multi-mode cavity filter according to claim **1**, wherein at least some of the first and second pluralities of coupling elements are patches formed on said surface of the piece of dielectric material.

7. The multi-mode cavity filter according to claim **6**, wherein at least some of the patches are of a regular geometric shape.

8. The multi-mode cavity filter according to claim **6**, wherein at least some of the patches are of an irregular geometric shape.

9. The multi-mode cavity filter according to claim **1**, wherein at least some of the first and second pluralities of coupling elements are probes arranged to abut said surface of the piece of dielectric material.

10. The multi-mode cavity filter according to claim **9**, wherein said probes have a substantially circular cross section.

11. A multi-mode cavity filter according to claim **9**, further comprising a shielding element associated with each probe.

12. A multi-mode cavity filter according to claim **1**, wherein at least some of the first and second pluralities of independent coupling elements are magnetic field generating elements.

13. A multi-mode cavity filter according to claim **12**, wherein said magnetic field generating elements are loop elements.

14. A multi-mode cavity filter according to claim **1**, wherein the first plurality of coupling elements comprises at least a first set of coupling elements configured to couple a first of said input signals to the piece of dielectric material for exciting a first of said two degenerate resonant modes of the dielectric resonator, and a second set of coupling elements configured to couple a second of said input signals to the piece of dielectric material for exciting a second of said two degenerate resonant modes of the dielectric resonator.

15. A multi-mode cavity filter according to claim **1**, wherein at least some of the first plurality of independent coupling elements are connected to each other in series.

16. A multi-mode cavity filter according to claim **1**, further comprising a primary transmission line configured to transmit signals to a plurality of secondary transmission lines branching off the primary transmission line; wherein each of the plurality of secondary transmission lines is configured to feed one of said input signals to a corresponding one of said first plurality of independent coupling elements.

17. A method of manufacturing a multi-mode cavity filter, the method comprising:

providing a dielectric resonator body incorporating a piece of dielectric material, the piece of dielectric material having a shape supporting at least two substantially degenerate resonant modes and one face having a surface; and

providing a coupling structure on said surface of said one face, said coupling structure including a first plurality of coupling elements arranged to couple input signals into the piece of dielectric material and a second plurality of independent coupling elements arranged to recover output signals from the piece of dielectric material, wherein the first plurality of independent coupling elements is distinct from the second plurality of independent coupling elements.

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